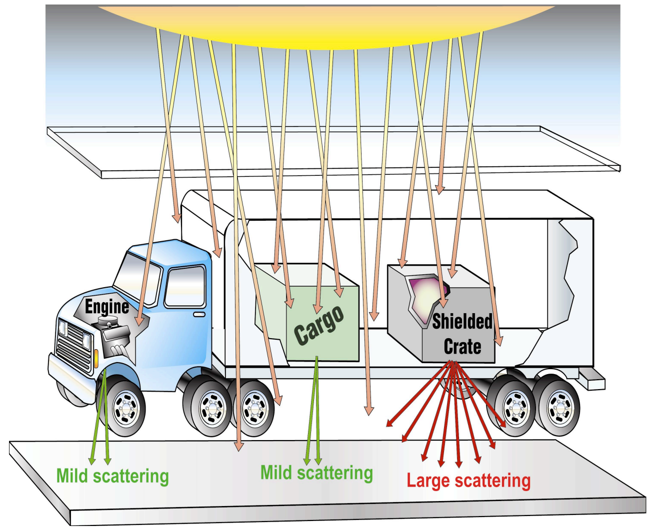
Larry Schultz (P-25); Mentor: Christopher Morris (P-25): **Cosmic Ray Muon Radiography**

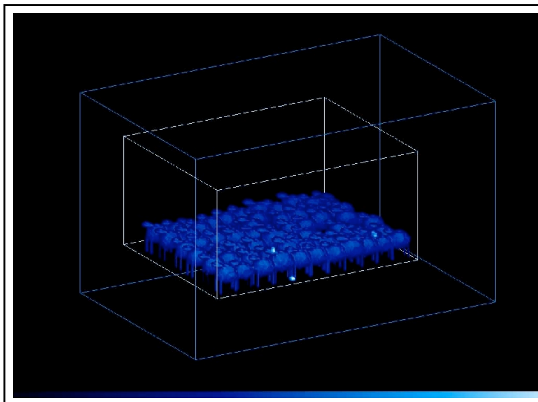
Cosmic-ray muon radiography is a new concept in the detection of fissile material. Atmospheric muons are generated when a proton or nucleus traveling in space strikes the Earth's upper atmosphere. Those particles change into pions, which subsequently decay into muons that continuously shower the Earth's surface at a rate of ~10,000 particles per square meter per minute. Muons eventually decay into electrons, but about 90% of the particles seen at the surface are muons. Muons have ~200 times the mass of electrons, and, thus, have a far greater ability to penetrate solid objects than do electrons.



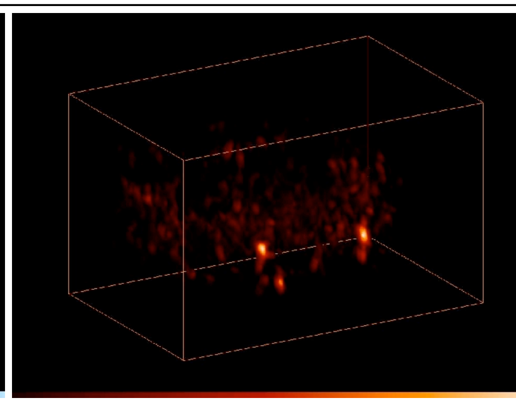
The goal of our project is to develop a system that takes advantage of this naturally occurring radiation to detect dense materials such as uranium or other radioactive materials (called high-Z materials because of their high atomic number). The general idea is to place two detector plates horizontally above a target object such as a shipping container or truck's cargo trailer (because muons are generated from particles originating in space, they generally propagate nearly vertically in the atmosphere). Two more detector plates would be placed below the target object (*e.g.*, buried underneath the roadway).

The top two detector plates will establish an incoming track for each muon that passes through the target container. The bottom two plates will detect the particle's exit track. As a muon moves through any material, two types of interactions occur: (1) it loses energy to the material through which it is moving, and (2) it is both displaced (the difference in horizontal distance between the entry track and the exit track) and scattered (the difference between the angle of entry and the exit angle). The denser the material with which the muon interacts, the more pronounced the multiple-scattering effect and energy loss become (to the point where some muons will not emerge from the material).

We have developed algorithms to track the incoming and emerging muon trajectories. The algorithms interpolate these trajectories backwards to determine their point of closest approach (PoCA) within the target container. When that PoCA distance is above a certain threshold (remember, the multiple-scattering effect is more pronounced as mouns traverse denser materials), it will indicate the possible presence of high-Z materials. These algorithms are based upon laboratory experiments and have been refined through computer simulations. Detection algorithms capable of dealing with real-world situations and anomalies are now being developed and refined.



Simulated container: a 2.4 × 2.4 × 6 m container with 3-mm-thick steel walls; 9 × 9 × 12 cm uranium "pigs" are hidden amongst 60 cm^3 water "sheep."



Simulated radiograph of the container at left: a 1 minute exposure, 90% detection probability, >>6 sigma rejection of false alarms, PoCA reconstruction.

Fissile materials could be detected more easily by probing suspect containers with neutron or gamma beams. However, that technique is severely limited by the need to avoid irradiating the general public. We feel that our technique will safely detect high-Z materials with processing times of ~1 minute with a very high degree of reliability, when used in tandem with other detection strategies. For example, a smuggler could attempt to mask the high-Z material from a muon radiography system by completely covering the container floor with a uniform layer of the illicit material (the scattering effect would also be uniform across the area of the container). However, the shielding requirements would make the cargo container suspiciously heavy. If the smuggler decided to leave the illicit cargo unshielded, a simple gamma-ray counter could detect the suspect material.